Mechanisms of Soil Carbon Sequestration with Reforestation of Tropical Pastures

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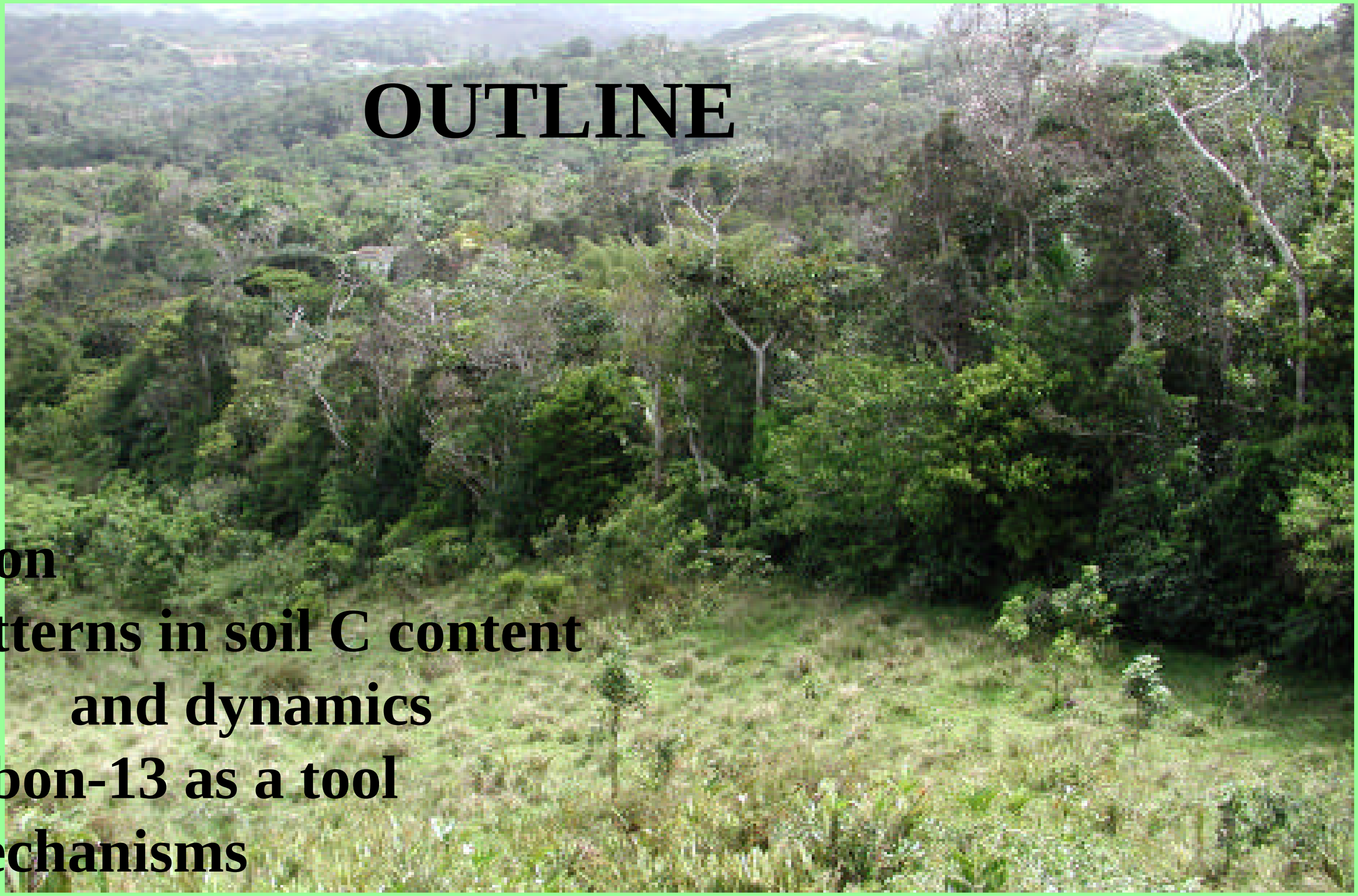
OUTLINE



- Introduction
- Part 1: Patterns in soil C content and dynamics
  - Carbon-13 as a tool
- Part 2: Mechanisms
  - Soil aggregation: physical protection
  - C Chemistry: chemical and physical protection
- Summary

View from below

- Better understanding of the belowground component of cycle of major greenhouse gas
- C sequestration in soils
- Rehabilitation degraded soils
- Bioremediation

Secondary forests dominate tropical landscape.

- Deforestation main land use studied in tropics
- Puerto Rico is at opposite end of land conversion: reforestation important process
- Reforestation important ecologically and economically: reclamation degraded soils, habitat restoration, forest goods and services

Research Objectives:

- To describe general pattern in soil C accumulation or loss with reforestation of tropical pastures
- To examine mechanisms that lead to soil C storage

CHRONOSEQUENCE APPROACH

ACTIVE PASTURES | **10 20 30 60 80** | **OLD-GROWTH FORESTS**

SECONDARY FORESTS

(years since pasture abandonment)




- Wet subtropical forest (400-600 masl).
- All sites are on same soil series (Los Guineos, Oxisols)
- 7 age classes, 3 site replicates per age for a total of 21 sites


PUERTO RICO
ATLANTIC OCEAN
0 20 km
0 12 mi
Isabela
Arecibo
Aquadilla
Manatí
San Juan
Bayamón
Luquillo
Fajardo
Rincón
Río Camuy Cave Park
Arecibo Observatory
Ciales
El Yunque
To Culebra
Caguas
Mayagüez
Puerto Rico
Cordillera Central
Humacao
Cayey
San Germán
Vieques
Boquerón
Ponce
Patillas
Arroyo
Guánica Dry Forest
Caribbean Sea
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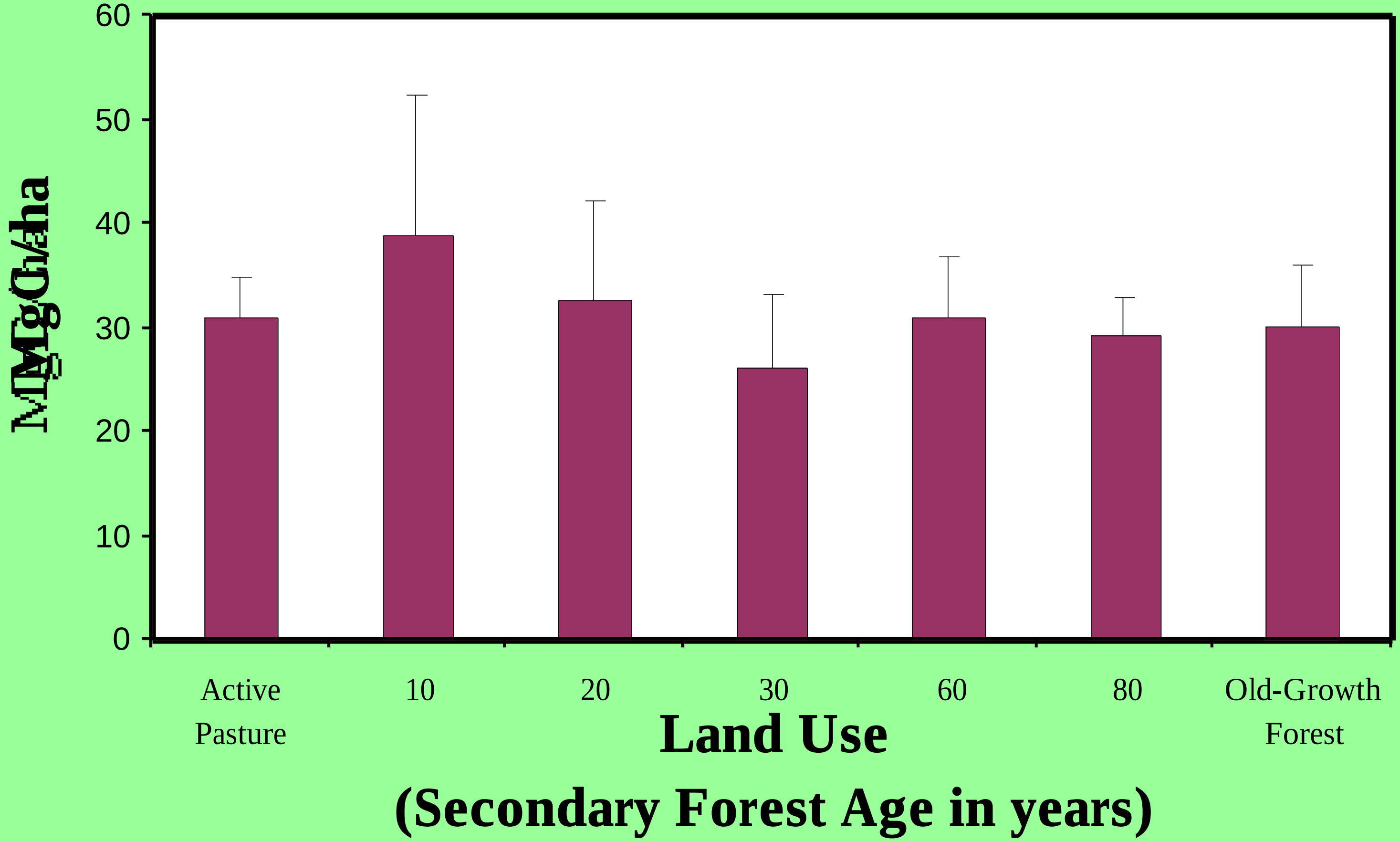
- **Objective 1 : Changes in soil C over forest succession**

Field Sampling

- Collect soils every 10 cm to a 1 m depth, 3 soil pits per site
- Collect roots, forest floor
- Litter baskets to estimate aboveground productivity and leaf samples for chemical analyses and decomposition studies

Soil C Content (MgC/ha) in 0-10 cm Depth



C Fractionation

- Experimental and modeling studies suggest that the total C pool is composed of different components, or “fractions”, with different residence times in the soil
- Attempts to separate total C pool into “fractions”, ie. stages of decomposition
- Operationally defined
- Common methods: particle size, density, aggregate-size, solubility, isotopes

Tools: Carbon Stable Isotopes

- 1.1% of C globally occurs as ^{13}C
- Isotopic fractionation, or differences in the $^{13}C/^{12}C$ ratio, occurs when a physical, chemical or biological process favors one isotope over the other.
- Useful tool for the:
  - study of landscape level changes in vegetation
  - reconstruction of past climatic, aquatic and atmospheric environments
  - study of trophic levels (*you are what you eat*)
  - study of carbon dynamics (sources, rates)
  - many other things… especially when combined with $^{15}N/^{14}N$ and $^{18}O/^{16}O$.

Carbon-13 in Plants

- Differences in C fixation pathways of **photosynthesis** results in differences in ^{13}C / ^{12}C of plants.
- During **C_4** and Kranz photosynthesis, less fractionation against ^{13}C than **C_3** plants.
- Tropical pasture grasses are **C_4** plants (average ∂ ^{13}C value of -12‰) and woody vegetation is **C_3** (average ∂ ^{13}C value of -25‰).

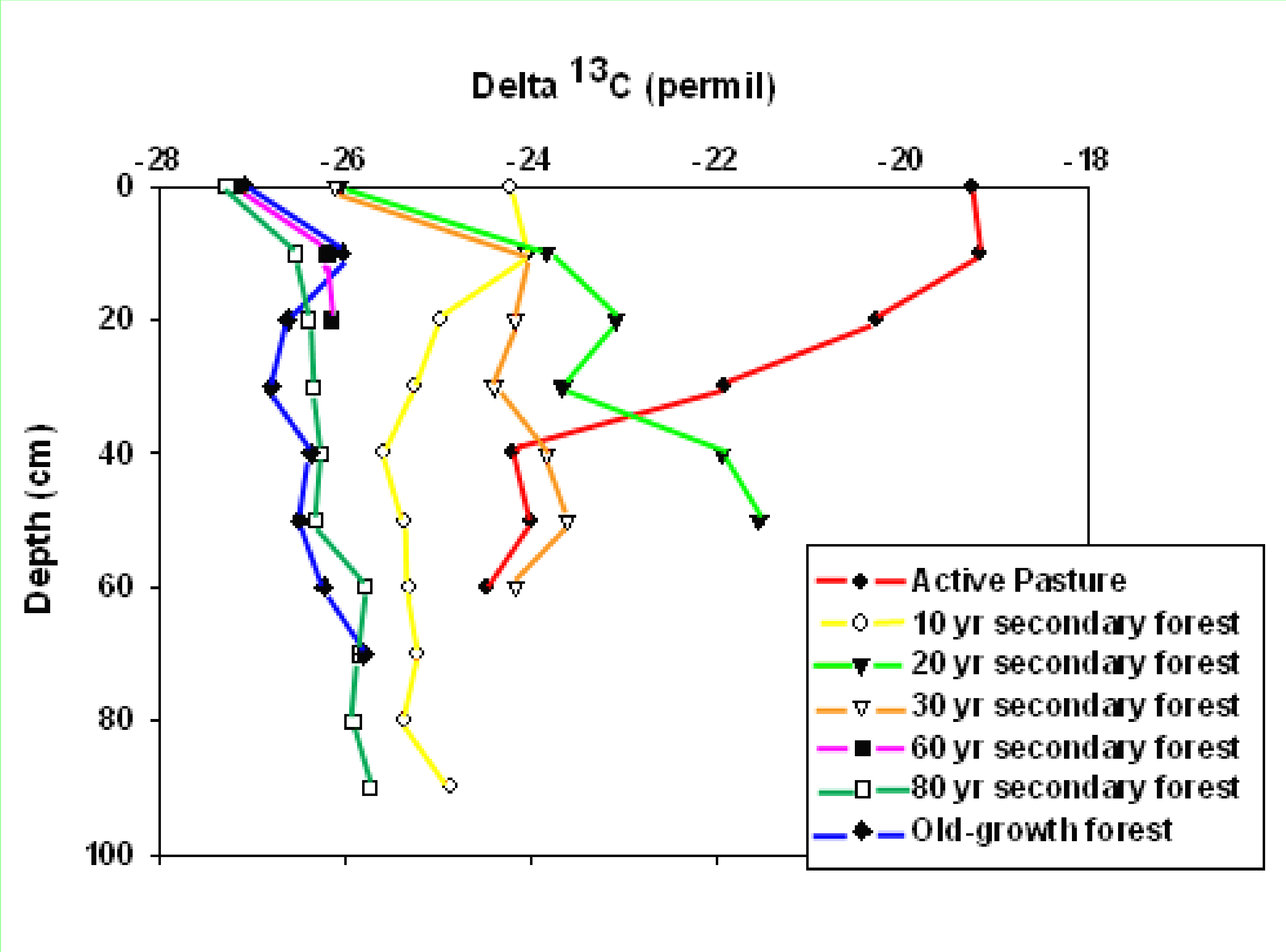
- Simple mixing model to determine proportion of C_4 vs. C_3 derived C in SOM pool:

$$\%C4 = (\delta - \delta_L / \delta_G - \delta_L) \times 100$$

$$\%C3 = 100 - \%C4$$

– *where δ is the $\delta\ ^{13}C$ of the soil sample in question, δ_L is the $\delta\ ^{13}C$ of a composite sample of forest floor and roots (or C3) , and δ_G is a composite sample of pasture grass tissues (C4).*

Soil δ ^{13}C-C (‰) with Depth



Assuming a $\_{L}$ of -17‰ and a $\_{G}$ of -26‰, at our 20 year old sites:

Soil depth (cm)	$\%C_3$	$\%C_4$	C_3/C_4
0-10	100	0	
10-20	76	24	3.10
20-30	67	33	2.06
30-40	74	26	2.79
40-50	55	45	1.21
50-60	50	50	1.01

Table 1. Example of proportion of C_3 and C_4 derived C for 20 year old sites.

Using ^{13}C to estimate turnover rates

Pasture		Secondary Forest
60 t C/ha	$\xrightarrow{\text{10 years}}$	80 tC/ha
100% C_4		54.5% C_4 = 43.6 t C/ha
		45.5% C_3 = 36.4 t C/ha

- After 10 years forest regrowth, 16.4 t C/ha of pasture-derived C was lost; rate of 1.64 tC/ha/y.
- Assumes: linear rate of loss, start with 100% C4 pasture, no fractionation during decomposition.

- Challenges using ^{13}C method:
  - unable to distinguish between residual "primary" forest C and new secondary forest C (both C_3)
  - uncertainties in $\delta^{13}C$ of end points, ages, turnover rates, land use history
  - assumptions inherent in "chronosequence" studies
  - simple mixing model (will try to improve)

I will also use ^{14}C and bomb carbon models to "date" soil C fractions and resolve uncertainties in turnover rates.

LAND USE HISTORY

- Need to know LUH for accurate turnover rates
- Difficulty in tropics
- Puerto Rico DISADVANTAGE: multiple land uses

•ADVANTAGE: records, records, records by both Spanish and U.S. govts.:

detailed maps; aerial photographs; ownership records; land tax documents; agricultural subsidy records

Objective 2 : Mechanisms of soil C storage

- Examine effect of changes in soil physical structure and plant litter chemistry on the formation of stable SOM.

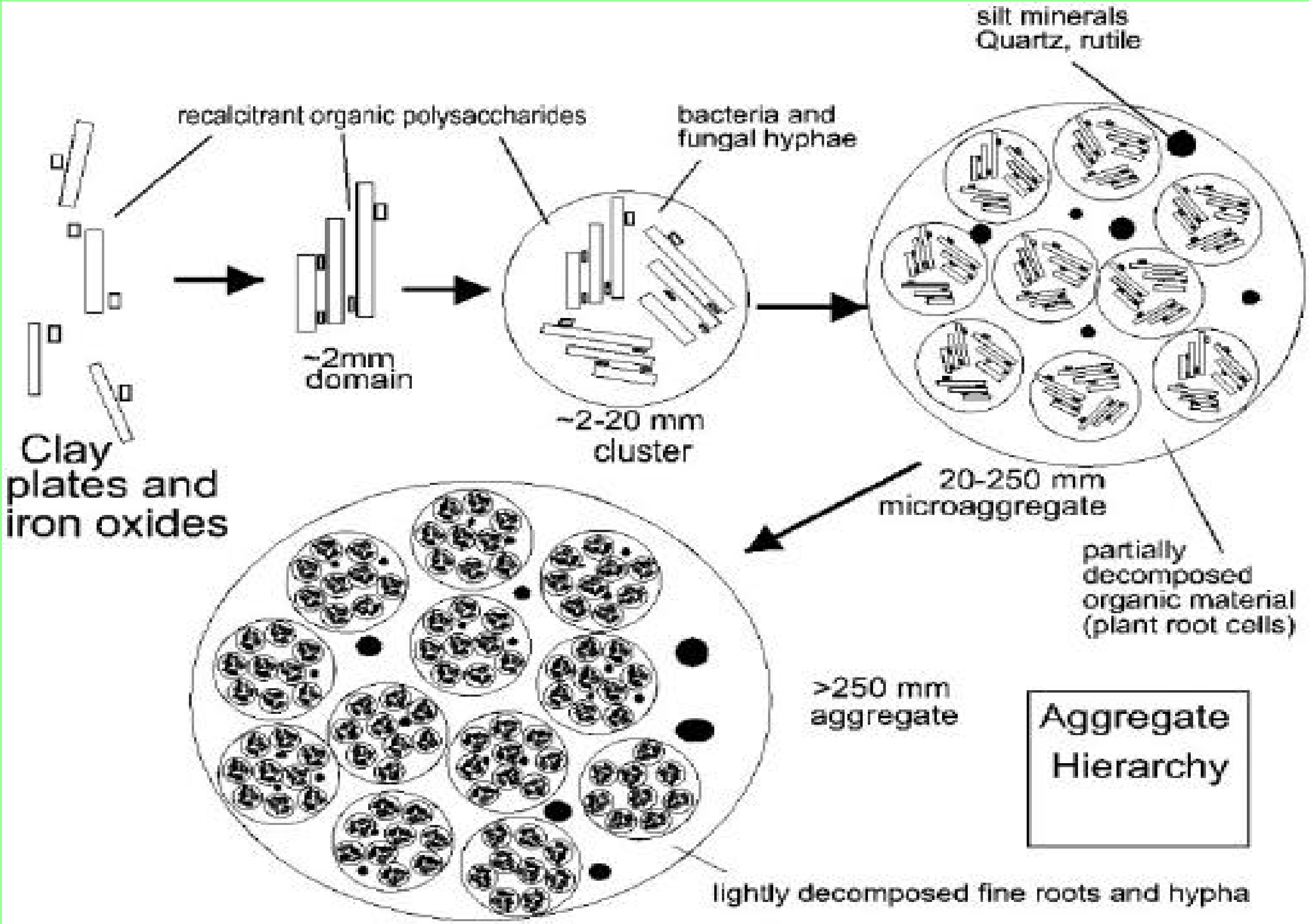
Hypotheses:

1.) The primary mechanism for soil C storage during reforestation will be the development of an aggregate hierarchy.

2.) The hydrophobic content of plant litter will be more important than traditional measures of litter quality in the formation of stable soil C.

H1: *The primary mechanism for soil C storage during reforestation will be the development of an aggregate hierarchy.*

- AGGREGATE HIERARCHY: model that describes the contribution of SOM as a stabilizing agent in the hierarchical binding of primary particles into microaggregates and microaggregates into larger aggregates (Tisdall and Oades 1982).



From G. Vrdoljak’s PhD Thesis, U.C. Berkeley

- The defining characteristics of AH are:

(1) a gradual breakdown of macroaggregates into microaggregates with increasing dispersing energy;

(2) an increase in C content with increasing aggregate size; and

(3) decrease in C turnover rates from macroaggregates to microaggregates (Six et al. 2000).

C protection within soil aggregates

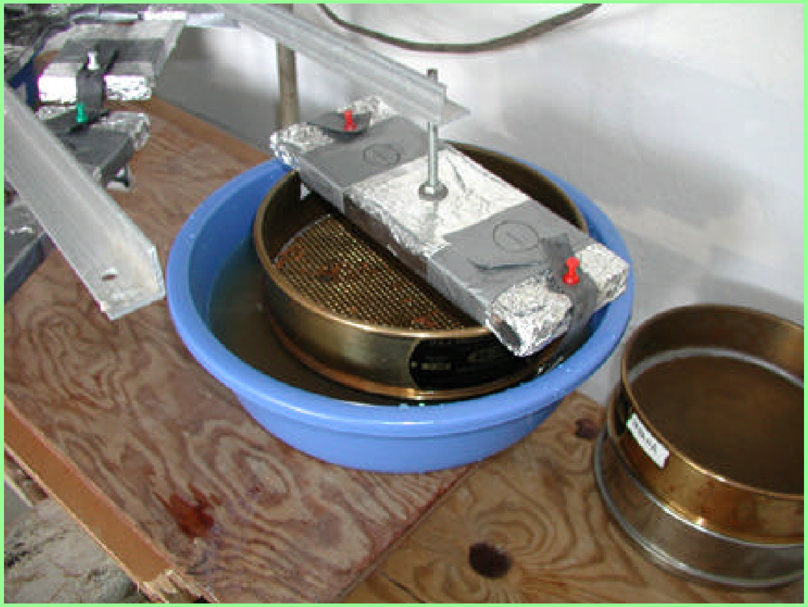
- C protected within microaggregates where accessibility to microbes is limited or anaerobic conditions may occur
- Lower C contents in cultivated soils attributed to disruption of soil aggregates
- C within aggregates is older than C on aggregate surfaces
- CO_2 lost from disturbed aggregates

Soil aggregation (cont.)

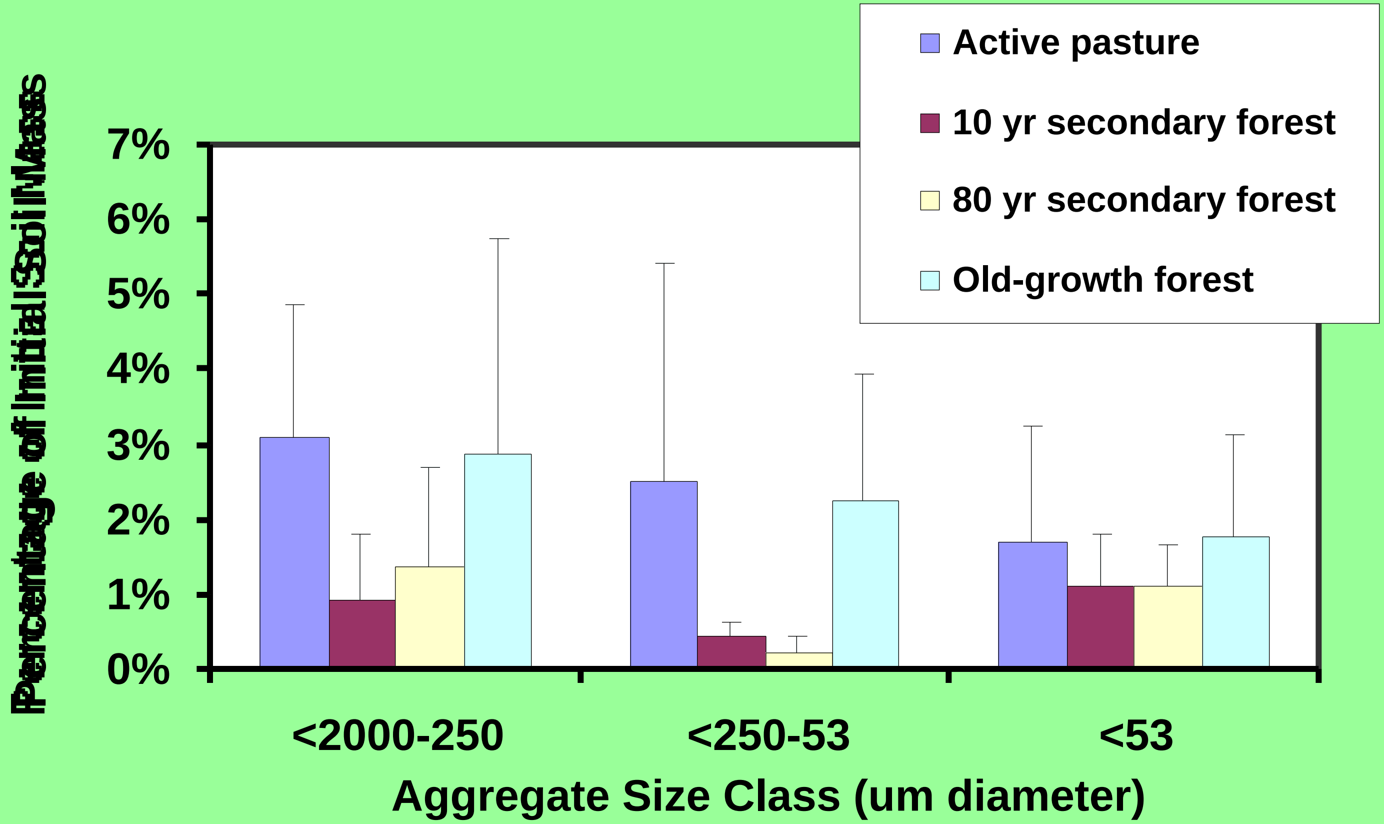
- Aggregate hierarchy thought not to be important in highly weathered tropical soils
- But recent evidence AH in Oxisols
- Recovery of aggregation post disturbance?
- Effect cattle vs pasture grasses

Soil aggregation (cont.)

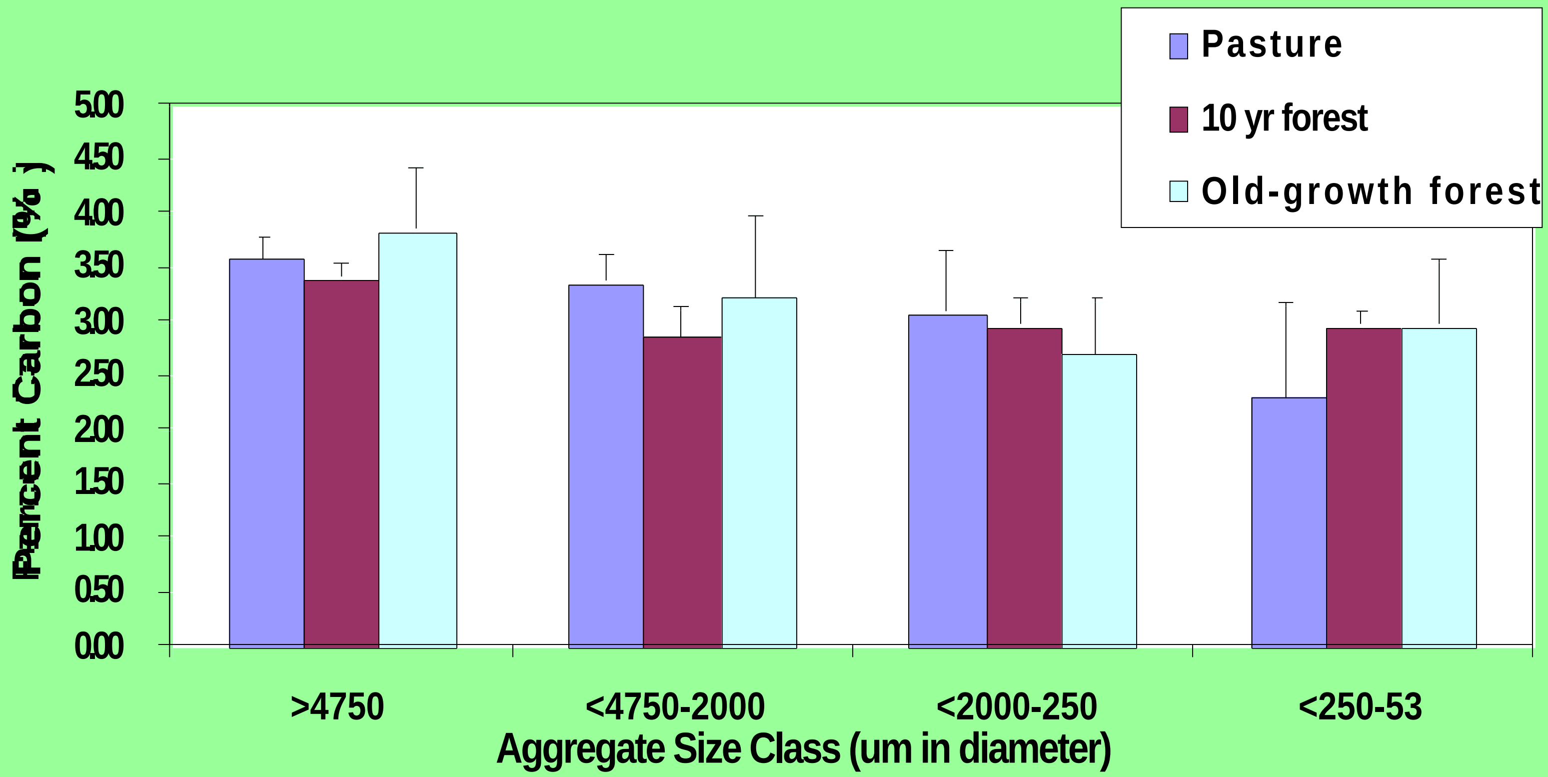
- *Approach:*
- Test for differences in water-stable aggregate size distribution across sites
- Test for presence of aggregate hierarchy:
  - expect total C and N to increase with size
  - expect C:N ratio to decrease from larger to smaller



Percentage of the initial mass of soil aggs > 4750 um that disassociated into smaller agg sizes and into primary particles.



C composition of different aggregate sizes



Future work with soil aggregation

- Modified method for highly weathered, very stable soils (increase slaking)
- Test for protection of C from decomposition within aggregate sizes:
  - Lab soil incubations: measure soil CO_2 and $^{13}CO_2$, normalized for total soil C from disturbed vs. undisturbed aggregates
  - estimate ages of C associated with different aggregate sizes using ^{13}C and ^{14}C

H2: *The hydrophobic content of plant litter will be more important than traditional measures of litter quality in the formation of stable soil C.*

- Litter C:N, lignin:N and lignin content as measure of decomposability
- But lignin degraded in soils
- Evidence of accumulation of nonpolar C in older soil C fractions
- Recent attention to plant and soil lipids as precursors to most stable SOM

Hydrophobicity (cont.)

- Plant lipids: secondary compounds, waxes, suberin, terpenoids.
- Theories of plant herbivory suggest production of these secondary plant compounds increases with forest succession
- Expect to see an increase in transition from pasture grasses to forest species
- But not a lot known yet about them….

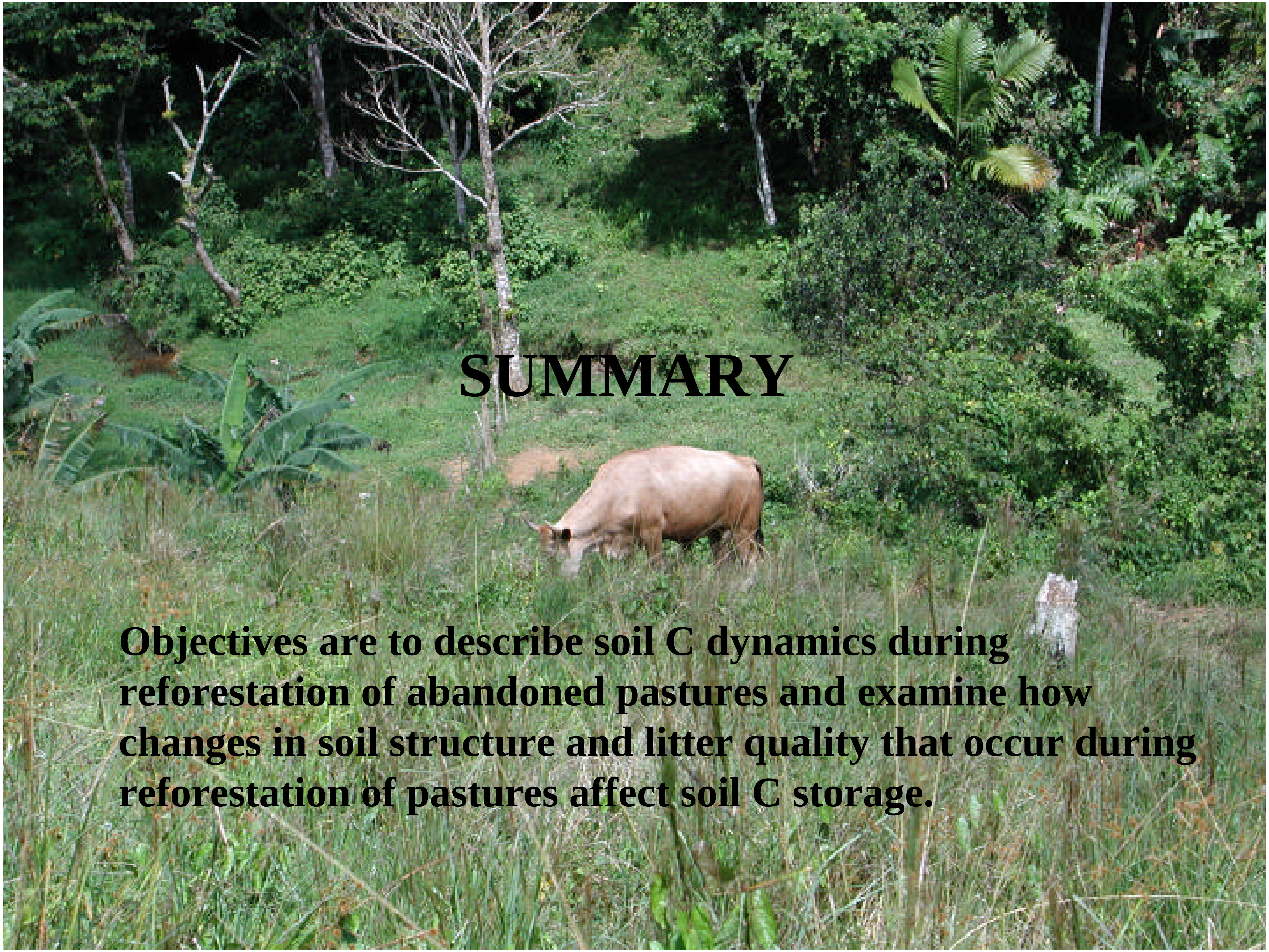
Hydrophobicity (cont.)

- ***Approach***

1. Characterize and quantify hydrophobicity of SOM and litter inputs: nonpolar organic extractions and ^{13}C-NMR
2. Test for correlations between chemistry plant inputs and SOM pools, SOM turnover rates, litter decomposition rates

3. How does chemical composition of SOM/DOM affect physical protection?

- Quantify sorptive capacity of soils at my sites
- Perform adsorption experiments with “native” and “transplant” DOM and SOM and litter extracts



SUMMARY

Objectives are to describe soil C dynamics during reforestation of abandoned pastures and examine how changes in soil structure and litter quality that occur during reforestation of pastures affect soil C storage.

Summer 2003 Plans

•Collect land use and land cover change historical data (continue with interviews and visit General Archives in San Juan)

•Finish site characterization: GPS, aboveground tree species composition and basal area for estimation of tree biomass

•Set-up site vs. litter quality decomposition experiment:

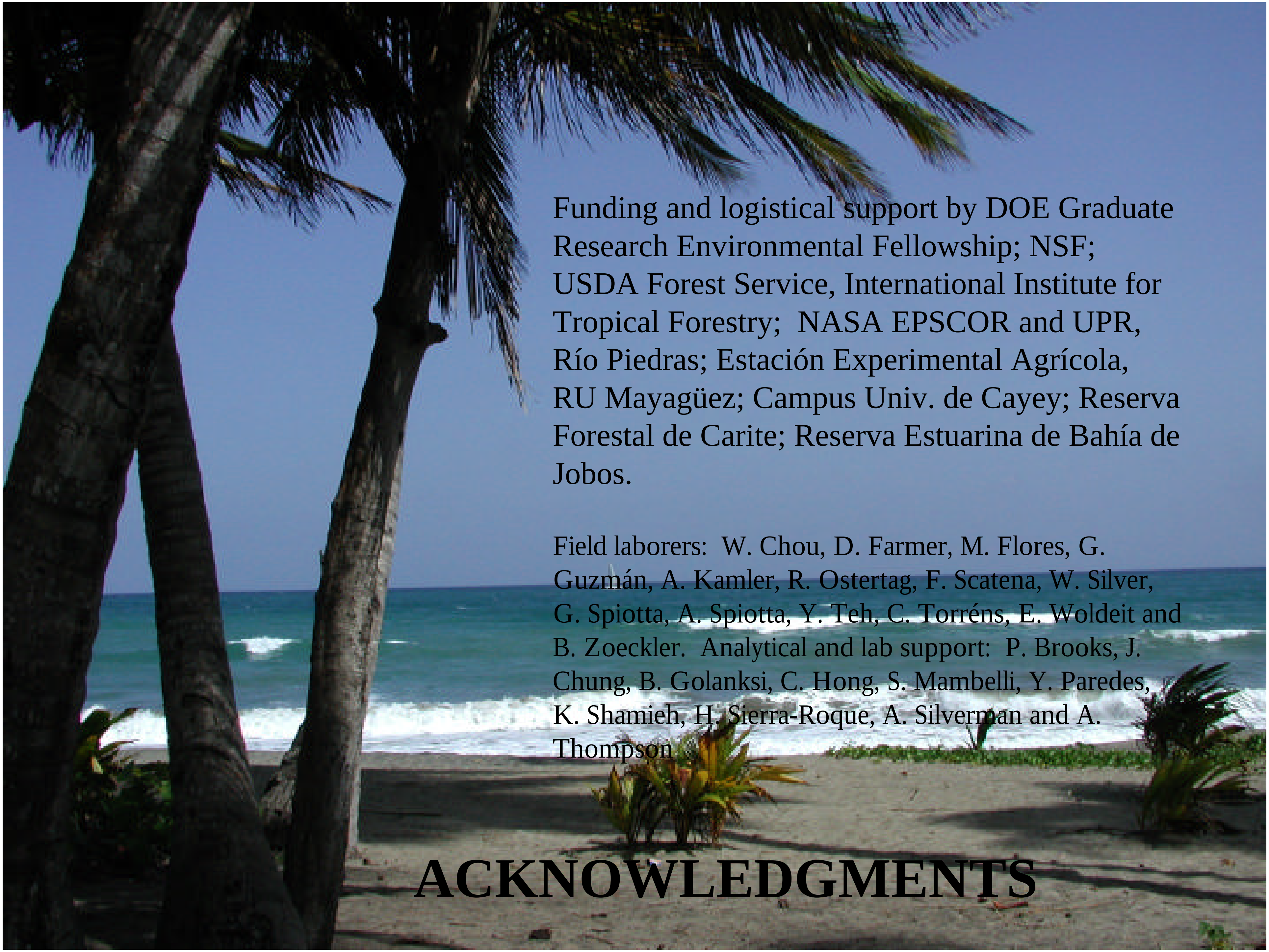
  -in situ and transplant mixed leaf litter decomposition bags

  -common leaf litter (or common wood substrate) across chronosequence

And then back to Berkeley to be a lab slave …..

Collaborators

- ***Dr. Whendee Silver*** (U.C. Berkeley): soil respiration and other trace gas production; litterfall rates
- ***Dr. Rebecca Ostertag*** (U. of Hawaii): foliar and root litter decomposition experiments (litter vs. site quality transplant)
- ***Dr. Margaret Torn*** (Lawrence Berkeley National Laboratory & GREF mentor): ^{13}C-CO_2 soil respiration and "bomb" (^{14}C) modeling



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